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THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME IX JANUARY 1899 NUMBER 1

ON THE SPECTRUM OF *a* AQUILAE AND ITS VELOCITY IN THE LINE OF SIGHT.[1]

By H. C. VOGEL.

I.

IN No. 2924 of *Astronomische Nachrichten* (July 1889), Professor Scheiner called attention to the peculiarity of the spectrum (of type I) of *a* Aquilae—that very faint and somewhat diffuse bands can be detected, in addition to the broad hydrogen lines. He was later able to show that these bands agree in position with groups of lines in spectra of the second type. He suggests[2] two explanations, along different lines, for the peculiarity of the spectrum. "For one, we may imagine that in consequence of decided cooling and condensation the constitution of the star has already reached considerable similarity with that of the Sun, and in such a manner that a few of the specially prominent metallic lines have not gradually appeared, but that the absorbing atmosphere is also similar in composition to the Sun. It would also have a powerful hydrogen atmosphere containing great quantities of magnesium vapor. *a* Aquilae would thus furnish an excellent proof of the gradual transition from the first to the second

[1] Translated from the *Sitzungsberichte* of the Berlin Academy, session of the physical-mathematical section on November 17, 1898.

[2] *Publicationen des Astroph. Obs. zu Potsdam*, Bd. VIII, II, p. 232, 1895.

spectral class, and thereby a strong support would be given for the physical meaning of the scheme of stellar classification."

"Another explanation of the spectrum of *α* Aquilae would be that it consists of two components, a spectrum of the second class being optically superposed upon one of the first class. Such an explanation could hardly have been assumed a few years ago, but today, with several very close binary systems already known, there is no objection to regarding *α* Aquilae as a double star with one component of the first class and the other of the second spectral class."

The view was also expressed by another, early in the nineties, that the spectrum of *α* Aquilae was to be regarded as the superposition of the spectra of two stars.

The Potsdam observations of the motions of stars in the line of sight could not furnish a support to the hypothesis of a binary nature of the star, as only three spectrograms of *α* Aquilae had been taken, which agreed well in the displacement.

During the years 1892 to 1895, M. Deslandres made observations in this direction and published them in *Comptes Rendus*, **121,** 629, 1895. From the very considerable variations in the values obtained for the velocity in the line of sight, in which no simple and regular period could be recognized, Deslandres reaches the conclusion that the star must be triple.

In looking over Deslandres' series of observations I was at first reminded of the early Greenwich observations of motions in the line of sight, and on a more thorough examination I was convinced that nothing could be deduced from them beyond a very considerable uncertainty of the observations themselves, probably caused by insufficient stability of the apparatus, and possibly also by the differences in setting on the broad and diffuse hydrogen lines in measuring spectrograms obtained on different dates, as would be expected from the difficult nature of the measurements of this object.

As I could not see any reason which compelled the acceptance of the variations as real and as indicating changes in the radial velocity, it seemed to me that a repetition of the observa-

tions would not be without interest. I therefore had a large number of spectrograms of the star taken with the large spectrograph previously used for motions in the line of sight.

Thus twenty-nine spectrograms are at my disposal, obtained in 1896 by Dr. Clemens, and in 1897 by Dr. Hartmann. The faint bands in the spectrum mentioned above are very distinctly shown on many of the spectrograms, which on the average were quite successful. On some of the especially good photographs the bands give the impression that they might be resolved into lines, but the coarseness of the silver grains prevented this when higher magnifying power was employed.

It seems to me that faint, diffuse bands in a star of the first class deserve special attention, for in spectra of this type only lines of great delicacy and almost without exception of extreme sharpness can be recognized in addition to the broad and more or less diffuse hydrogen lines. Professor Scheiner's observation that these bands can be almost certainly identified with groups of lines of the spectrum of the second type, is of great importance. The hypotheses above mentioned require, however, an extension, for they do not explain why the groups of lines should appear as diffuse bands. A star spectrum of type II can never come to resemble the band spectrum of *α* Aquilae by mere faintness of its light, since the groups of lines would not appear like bands in a very faint star, but only certain of the individual stronger lines would come out while the faint groups of lines would almost entirely disappear. There must, therefore, be some special conditions in this spectrum, and I have tried to reproduce experimentally the appearance of the spectrum of *α* Aquilae. If the lines in the solar spectrum are broadened by a doubly refracting prism, or if all the lines of the spectrum are doubled by further rotation of the prism, it is striking how strongly the individual groups of lines appear. By using a cylindric lens to produce a slight broadening of all the lines of the solar spectrum we can succeed still better in producing a spectrum similar to that of *α* Aquilae. A similar result may also be reached simply by imperfect focusing. Then there appear

not only faint, diffuse bands no longer resolvable into lines, but there also develop maxima of intensity in these, on account of the partial superposition of the broadened lines which, when they merge with the stronger lines of a group, produce a displacement of the maximum of intensity of the group, and thereby a strong alteration in the appearance of the spectrum.

We finally succeeded in producing with the large spectrograph, by imperfectly focusing the plate, pictures of the solar spectrum in which the close lines so ran together as to produce a spectrum resembling the band spectrum of *α* Aquilae. Dr. Hartmann undertook a comparison of one of these spectra with two plates of *α* Aquilae in which the faint bands were especially well seen, and the following list of broad, diffuse bands observed by him in the spectrum of *α* Aquilae stands in good agreement with Professor Scheiner's earlier researches :

425.0 μμ	Absorption band (Fe).	438 μμ	Bright place.
426.0	" " (Fe).	438.5	Two absorption lines, diffuse (Fe).
427.2	" " (Fe).	440	Bright place.
431	G group hardly indicated. (G is very weak, not only on the two plates here used, but also on four further plates on which the bands are very well seen.)	441.5	Absorption line.
		442	Bright place.
		444	" "
		444.3	Absorption band (Fe).
		447.5	Bright place.
		448	Broad absorption line, diffuse (Mg).
432.5	Absorption band (Fe).		
434.1	$H\gamma$; broad, diffuse.	448.7	Bright place.
435	Absorption band.	449–450	Absorption band.
436.5	Bright place ; broad.	453	" "
437.5	Absorption band.		

It is noticeable that regions sparse in lines in the diffuse solar spectrum give the impression of bright strips as in the spectrum of *α* Aquilae. The exact comparison of the two spectra leads, however, to the view that the agreement is not perfect, in particular that the G group is hardly indicated in the spectrum of *α* Aquilae, while it still comes out strongly in the diffuse solar spectrum. This is in full accord with my charac-

terization of the spectra of class I*a* 3, which contain a large number of metallic lines beside the broad and strongly dominant hydrogen lines, but in which, however, in contrast to spectra of class II*a*, the group G is only faintly developed.

In this I find support for the view that in this case the superposition of a spectrum of class I*a* on one of class II*a* is not to be assumed. Aside from details, however, the similarity is so great between the solar spectrum produced with imperfect focusing and that of *α* Aquilae that I do not care to doubt that the cause of the diffuse bands in the spectrum of *α* Aquilae is to be sought in the running together of close lines caused by a broadening of the individual lines.

How this broadening is produced is a second question, and more difficult of solution.

Scheiner's first hypothesis should be so extended as to state that the conditions of temperature and pressure in the atmosphere of a star which produce a marked broadening of the hydrogen lines, as shown by most stars of class I*a*[1], also cause a broadening of the lines of other metals. The spectrum of *α* Aquilae would nevertheless remain very isolated (according to Scheiner *β* and *δ* Leonis and *β* Cassiopeiae exhibit a spectrum similar to that of *α* Aquilae[2]) ; for, as already said, excepting the hydrogen lines, most of the metallic lines are very sharp in almost all spectra of stars of class I*a*.

The second hypothesis that the spectrum of *α* Aquilae is of type I*a*, on which that of a companion of type II*a* is superposed, can hardly be extended by the assumption that this second spectrum possesses broadened lines as a result of peculiar

[1] I refer here to my newly revised classification of stars of the first spectral class. *Sitzungsberichte* 1895, p. 947 ; this JOURNAL, **2**, 333–349, 1895.

[2] *Loc. cit.*, pp. 231 and 233. I confirm the similarity between the spectra of *β* and *δ* Leonis obtained here and that of *α* Aquilae. But few bands can be perceived, which are still fainter than in *α* Aquilae. In our two spectrograms of *β* Cassiopeiae, however, very numerous narrower bands can be perceived which give the impression of lines. They are all striking in being diffuse on both sides, but are distinctly separated from each other. With low dispersion the spectrum shows sharp, rather wide lines, and since the hydrogen lines are also quite sharp, the spectrum is similar to that of *α* Cygni.

conditions of pressure and temperature, since no such a spectrum of type II has yet been observed, and there is no ground for the assumption of unusual conditions of the atmosphere of this companion star.

I would now point out the possibility of explaining the breadth of the lines in this case as a consequence of the rotation of the star. If we suppose that the axis of rotation does not lie exactly in the line of sight or make a very acute angle with it, those rays which proceed from the approaching limb of the star will suffer a displacement in the spectrum toward the violet, and those from the opposite limb toward the red. A spectral line will therefore appear broadened by an amount corresponding to the displacement of the lines due to the relative velocity of the two limbs, if the light from all parts of the visible surface of the star simultaneously enters the slit of the spectroscope. The lines will appear diffuse, since so much the less light from the portions of the surface will reach us the more the component of the motion of these portions in the line of sight nears its maximum.

Abney was the first, in 1877, to call attention to the effect of the rotation of a celestial object upon its spectrum. He sought to explain thus the broadening of the hydrogen lines in the spectra of type I*a*, and, indeed, to deduce from the amount of the broadening an average period of rotation of these stars. I then pointed out [1] that this reasoning, entirely correct in theory, is not permissible in explaining the broad hydrogen lines in the spectra of the first type, because, firstly, the intensity-curve of the broadened lines in the star spectra in no wise agrees with the calculated curve for lines broadened by rotation; and, further, because in order to obtain a broadening corresponding to that of the hydrogen lines in the spectra mentioned (expressed in wave-lengths this amounts to from 0.5 $\mu\mu$ to 1.0 $\mu\mu$), we should reach the highly improbable velocities of from 170 km to 335 km for a point on the star's equator. Finally I called attention to the fact that this broadening by rotation must affect

[1] *A. N.*, 90, 71–75, 1877.

all the lines in the spectrum, and that sharp, fine lines cannot be present along with the broad hydrogen lines—as they actually are shown in class I*a*—if the explanation is permissible.

According to the observations of that time I was entirely correct when I wrote in 1877: "The question whether there are stellar spectra in which all the lines are broad and diffuse is to be answered decidedly in the negative." With the increased perfection of optical apparatus and with the development of the application of photography, valuable beyond all expectation, our point of view has shifted, and for the above considerations I should like to cancel the above statement as applied to *α* Aquilae. Thus a field is opened for the explanation of the broadening of lines by rotation, and I consider it quite probable that it applies for the stars *α* Aquilae, *β* and *δ* Leonis, and perhaps also for *β* Cassiopeiae.

In the case of *α* Aquilae, I find further support for this view, because, as I shall show later on, a periodic motion of the star cannot be deduced from the recent observations, such as could occur if a companion existed of a mass not too small relatively to the principal star.

Summarizing, I would express the following view as to the spectrum of *α* Aquilae: The spectrum belongs to class I*a* 3; the hydrogen lines are much broadened as a result of the conditions of temperature and pressure in the star's atmosphere, and they are rendered a little more diffuse by the star's rotation. In addition to the hydrogen lines, numerous metallic lines are present, and the composition of the atmosphere of the star approaches that of stars of the second spectral class. All of the lines are, however, broadened in consequence of a strong rotation, so that close lines form separate diffuse bands, while the stronger, isolated lines appear diffuse.

In order to give an idea of the magnitude of the velocity of rotation requisite to produce said effect of the running together of close lines into bands, I present the following considerations.

In regions of the solar spectrum where lines are numerous, the difference in wave-length of the individual lines averages

about 0.04 $\mu\mu$. On the supposition that the lines are at a uniform distance apart, a velocity of rotation of 13.5 km would suffice to broaden the lines so that they would theoretically touch each other. In consequence of the extremely slight intensity of the lines at their edges, they would still appear separated, but with twice that value of the velocity of rotation, an actual merging of the lines would be expected, with the assumed distances as above.

If we admit the possibility of a motion of rotation of that amount, we are forced to meet the question why only three or four stars have thus far been observed with spectra of such character as to lead us to infer a rapid rotation. It should be first pointed out that observations for deciding this matter are possible only under very high dispersion; so that at present only fifty of the brightest stars which were observed at Potsdam can come into question. It is also to be remembered that the further condition enters, as in the case of close double stars which can only be recognized as such by the aid of the spectroscope, that in the one the orbital plane, and in the other the equator, must make a very acute angle with the line of sight.

I turn from these considerations, which it seems to me ought to heighten interest in α Aquilae, to the determinations of the star's radial velocity made here in the last two years.

II.

To the following list of the observations of the velocity of α Aquilae in the line of sight, recently made at Potsdam, I have only to add that the displacement of the $H\gamma$ line in the star spectrum from the corresponding hydrogen line of the comparison spectrum on the photographic plate is expressed in revolutions of the micrometer screw of the measuring apparatus already known from our earlier observations ($1^r = 0.25$ mm). They are the mean of at least four measures. The measurements were carried out by the method described by me in Part I of the seventh volume of the Publications of the Astrophysical Observatory and made clear by figures.

Date of plate	Displacement in revolutions		Remarks
	v. r.	v. l.	
1896			
August 5	— 0.092	— 0.116	*Hγ* weak, very diffuse. Measure not easy.
9	— 0.116	— 0.111	Very good plate. Measure very sure.
	— 0.106		
11	— 0.110	— 0.113	Plate strong and good. Measure very sure.
27	— 0.075	— 0.063	Very sure measure.
September 16	— 0.047	— 0.041	Strongly exposed, but very suitable for measuring.
27	— 0.064	— 0.043	Spectrum broad, less suitable for measuring. Plate otherwise very pretty.
	— 0.028		
28	— 0.050	— 0.037	*Hγ* weak and broad. Pointing difficult.
29	— 0.068	— 0.054	Good plate, strongly exposed. Measure sure.
	— 0.049		
	— 0.053		
	— 0.039		
October 9	— 0.033	— 0.011	Good, somewhat faint. *Hγ* broad, but allows of sure measures, with a broad covering strip.
		— 0.026	
10	— 0.025	— 0.055	Very good plate. *Hγ* very broad.
	— 0.024		
12	— 0.030	— 0.038	Strong. Good plate.
	— 0.030		
22	— 0.015	— 0.041	Very good plate.
24	— 0.044	— 0.056	Weak plate. *Hγ* somewhat broad. Weight ½.
		— 0.021	
November 4	— 0.081	— 0.046	Strong and very good plate.
	— 0.027		
	— 0.053		
5	— 0.045	— 0.030	Very good for measurement.
6	— 0.062	— 0.035	Very good for measurement,
9	— 0.068	— 0.067	Plate weak. Setting on *Hγ* difficult. Weight ½.
10	— 0.051	— 0.042	Plate strong, good. Measure very sure.
	— 0.062		
12	— 0.048	— 0.048	Somewhat weak, but good to measure.
13	— 0.047	+ 0.015	Very good plate, linear. Comparison line sharp and strong. The different pointing in the second position of the plate is surprising.
	— 0.018		
	— 0.037		
17	— 0.028	— 0.057	Good plate. Very sure setting on *Hγ*. The comparison *Hγ* seems double, a proof of a slight displacement of the spectrum during the exposure.
26	— 0.066	— 0.051	Excellent plate. The artificial *Hγ* gives the impression of being double.
December 3	— 0.054	— 0.061	*Hγ* broad in star, setting not easy.
		— 0.067	Comparison line double.
1897			
November 9	— 0.048	— 0.014	Spectrum broad. Measure very good.
10	— 0.041	— 0.023	Plate and measure fairly good.
11	— 0.042	— 0.020	Very good plate. Comparison *Hγ* somewhat weak and diffuse
13	— 0.035	— 0.023	
		— 0.040	
20	— 0.055	— 0.025	Comparison line very weak. The spectrum should be somewhat stronger. Measure nevertheless quite sure.
December 15	— 0.078	— 0.086	Spectrum very weak. Comparison line
		— 0.109	very faint. Fairly measurable under cloudy sky. Weight ½.

The measurements were so arranged for each plate on different days that the more refrangible end of the spectrum was placed once toward the right and then toward the left end of the microscope table, in order to eliminate the systematic errors of pointing (see p. 108, *loc. cit.*). The position of the plate is indicated by the columns v. r. and v. l. (violet left.). If several series of measures were made on a plate on the same day with the use of different strips for covering the $H\gamma$ line in the star (see p. 38, *loc. cit.*), the values are bracketed; if not, a second, entirely independent series of measure was made on another day.

A minus sign indicates a displacement of the star spectrum toward the violet of the comparison spectrum, corresponding to the approach of the star toward the Earth.

Date	Displacement	Velocity rel. to Earth	Red. to ⊙	Velocity rel. to ⊙
1896				
August 5	—0.104 rev.	—23.3 km	—6.2 km	—29.5 km
9	0.111	24.9	7.9	32.8
11	0.112	25.1	8.7	33.8
27	0.069	15.5	14.8	30.3
September 16	0.044	9.9	21.0	30.9
27	0.045	10.1	23.5	33.6
28	0.044	9.9	23.7	33.6
29	0.053	11.9	23.8	35.7
October 9	0.026	5.8	25.2	31.0
10	0.040	9.0	25.3	34.3
12	0.034	7.6	25.5	33.1
22	0.028	6.3	25.9	32.2
24	0.041	9.2	25.9	35.1 (Wt. ½)
November 4	0.050	11.2	25.2	36.4
5	0.038	8.5	25.1	33.6
6	0.049	11.0	25.0	36.0
9	0.068	15.2	24.6	39.8 (Wt. ½)
10	0.049	11.0	24.5	35.5
12	0.048	10.7	24.2	34.9
13	0.010	2.2	24.0	26.2
17	0.043	9.6	23.2	32.8
26	0.059	13.2	21.3	34.5
December 3	0.059	13.2	19.3	32.5
1897				
November 9	0.031	6.9	24.7	31.6
10	0.032	7.2	24.5	31.7
11	0.031	6.9	24.4	31.3
13	0.033	7.4	24.1	31.5
20	0.040	9.0	22.8	31.8
December 15	—0.088	—19.7	—15.3	—35.0 (Wt. ½)

The foregoing table contains the velocity of the star relative to the Earth, obtained from the above mean values of the displacement with the value of the velocity corresponding to one revolution of the screw given on p. 33 of the seventh volume of Potsdam Publications, viz., g = 30.18 geog. miles = 223.95 km. The velocity relative to the Sun is deduced with the aid of a table previously published (*loc. cit.*, p. 92).

The velocity per second of *α* Aquilae relative to the Sun from the mean of the above observations is

$$-32.9 \text{ km} \pm 0.3 \; (-4.44 \pm 0.04 \text{ geog. miles}).$$

There are no indications whatever of a periodic variation of this value. The probable error of the mean of series of measures made on the same plate on two different days amounts to ± 1.6 km, whence follows ± 2.2 km as the probable error of the mean of a series of measures made on one plate on a single day. This value is somewhat smaller than it was on the average in the earlier observations made with the same method of measurement. This may be due to the fact that the spectrum plates of *α* Aquilae are on the average very good and that the measures were executed with very special care.

The probable error of the mean of a series of measures on one plate would be still somewhat less if we had taken into account the personal error in setting the micrometer thread on the strip which covered the $H\gamma$ line in the star. In my case this error is slight, as was shown in the earlier researches (*loc. cit.*, p. 109). With a cover strip 0.114 mm wide the correction amounted to + 0.0009 mm. A difference of about 0.0018 mm would be expected between the series of measures with v. r. and v. l., since the strip most used for covering in the case of *α* Aquilae was of similar width (0.120 mm), and the values with v. r., taken absolutely, should be greater than those with v. l. A difference in this sense is, in fact, found, amounting in the mean to 0.005 revolutions, or 0.0013 mm.

The observations of the radial velocity of *α* Aquilae made here in 1888 gave − 4.97 geog. miles as the mean of the measures by myself and Scheiner. An unusual difference of 0.77

geog. miles appears between Scheiner's measures and my own, which agreed well among themselves. *a* Aquilae is one of the eight stars of the forty-seven observed by Professor Scheiner and myself for which the results differed by more than three-fourths of a mile. As my earlier measures differ also from the new ones just given, and as conclusions might possibly be drawn therefrom of a change in the star's velocity, I have remeasured the old plate, but I did not succeed in getting exactly the same mode of pointing (*Auffassung*) as before. The new measures gave:

1888	v. r.	v. l.	
September 27,	−0.042^r	−0.047^r	Plate strong, good to measure.
October 31,	−0.036	−0.036	Spectrum made unusually broad.
November 5,	−0.048	−0.041	Measure not easy.

From these we get the following results:

1888	Displacement	Velocity rel. to Earth	Red. to ⊙	Velocity rel. to ⊙
September 27	— 0.045^r	— 1.36 g.m.	— 3.17 g.m.	— 4.53 g.m.
October 31	— 0.036	— 1.09	— 3.45	— 4.54
November 5	— 0.045	— 1.36	— 3.39	— 4.73

The resulting mean value of the velocity per second relative to the Sun is —4.60 geographical miles, a value in good agreement with Scheiner's determination (—4.58 g. m.) and also with my more recent observations. There is no reason for regarding the earlier measures of the 1888 plates as inferior to these recent measures of them, since differences in the mode of pointing upon the $H\gamma$ line may very easily occur for the same observer at different times, and hence the mean result of the three series of measures is to be taken for the observations in 1888, namely, -4.86 ± 0.09 geographical miles or -36.1 ± 0.7 kilometers.

I now give the observations of M. Deslandres as they appeared in *Comptes Rendus*, Tome CXXI.

In a note on p. 630 M. Deslandres remarks that the maximum error of an observation with weight 5 is to be taken as 3 km.

He does not indicate how he arrived at the determination of the weights, and all data are also lacking by which a somewhat closer examination of the observations could be made. The measurements are referred to hydrogen lines $H\gamma$ and $H\delta$; and in some cases iron or calcium was used for the comparison spectrum. It is not stated whether the latter proved to be of advantage. I should doubt it, however, because the lines in the spectrum of α Aquilae are so diffuse, as we have often said, that between $H\beta$ and $H\delta$ no lines except those of hydrogen and the Mg line at λ4481 can be identified with known lines.

OBSERVATIONS OF THE RADIAL VELOCITY OF α AQUILAE BY M. DESLANDRES. VELOCITY TOWARD THE SUN IN KILOMETERS PER SECOND.

Date		Velocity	Weight	Date		Velocity	Weight
1892				1895			
July	8	−23.3	2	July	12	−25.3	5
August	6	−12.4	3		16	−37.4	5
	12	−32.6	4		17	−35.0	5
	13	−25.6	4		23	−17.6	5
	31	−18.5	3		25	+11.4	5
September	12	−11.8	1	August	9	−21.4	5
	19	−38.4	3		13	−12.2	5
October	3	−18.5	2		14	−13.1	4
1893					16	−1.9	5
July	6	−19.3	4		17	−22.9	4
	7	−15.6	5		19	−28.2	5
	19	−18.0	5		20	−28.6	5
1894					21	−19.8	5
August	11	−36.5	1		22	−29.0	5
October	17	−28.4	3		24	−28.5	5
1895					26	−33.8	5
May	28	+10.9	4		28	−24.2	5
	30	−11.3	5		29	−35.1	5
June	8	−14.9	5		30	−18.4	5
	11	−14.9	4		31	−6.3	5
	15	−9.8	5	September	2	−29.0	2
	17	−13.4	3		4	−20.1	4
	22	−16.1	3		6	−30.5	5
	24	−8.2	5		9	−24.0	5
	25	−3.0	5		16	−33.8	5
	26	−4.6	5		20	−13.5	5
July	3	−11.0	1		23	−10.7	5
	8	−12.7	5		24	−27.8	5
	9	−18.1	4		25	−7.2	4
	10	−27.8	2				

The weighted mean of the 56 observations gives -18.9 km as the velocity of α Aquilae relative to the Sun. The probable error of the mean is ± 1.0 km, and that of the single day's determination with weight 5 is ± 7.0 km.

M. Deslandres is evidently in error as to the accuracy of his observations, which explains his attempt to regard the large differences among the observations as periodic variations. The three largest values of the velocity were obtained on July 16, 17, and August 29, 1895, and probably gave the basis for the assumption of a principal period of 43 days. An equally large velocity would be expected in the early part of June if the period were uniform, but it is not found. The case is the same with the minimum values falling in the intervals. On June 25, therefore, half a period back, such a minimum is to be found, but a second one ($+11$ km) was observed on July 25 instead of the first days of August. The value on August 9, -21.4 km, is close to the mean of all the observations, and a third minimum is not present on September 19. The fact that two days after the maximum of -35 km, on August 29 the velocity fell to -6 km, to rise again to -29 km on September 2; that the observations of July 23 and 25 differ by 29 km, and those of August 16 and 17 by 21 km; and that the observations on three successive days (September 23, 24 and 25) make jumps of 17 and 21 km respectively, ought to have led M. Deslandres to conclude that the accuracy of his observations was less than he had presumed, possibly deduced from the inner accordance of the measures on the same plate. Instead of this he sought to bring the observations into agreement by the assumption of a second period of about five days, and finally, since this was not successful, he assumed that the amplitude and period are variable and that α Aquilae is at least a triple star.

I believe that my observations have sufficiently demonstrated the futility of the endeavor to derive a periodic variation of the component in the line of sight of the motion of α Aquilae.

OBSERVATIONS OF THE LEONID METEORS, NOVEMBER 10–16, 1898.

By George C. Comstock.

In observing the Leonid meteor shower of 1898 my attention was primarily directed to a determination of the relative density of those portions of the swarm traversed by the Earth, and for this purpose I have made an enumeration of the Leonids seen during alternate half hour intervals extending from midnight to daybreak of each clear night from November 10 to November 16, inclusive. In this enumeration I was very materially assisted by Mr. E. F. Chandler, a graduate student of astronomy in the University of Wisconsin, whose observations are indicated below by the signature Ch., while my own are designated by the letter C.

Each observer was careful not to include in the enumeration any meteors save those which clearly proceeded from the Sickle in Leo, but it is probable that a certain number of fainter meteors have been included in the counts which are not properly Leonids, since in their case the appearance of the meteor furnishes no clue to its character. For the brighter meteors mistakes of identification should be very infrequent. The attention of the observers was confined to the constellation Leo and so much of the surrounding region as could be surveyed conveniently by a single observer, and this may be roughly estimated as that part of the sky between the altitudes 10° and 80°, and extending in azimuth 45° on either side of the radiant. On a single occasion, noted below, simultaneous observations were made by Mr. Chandler to the north and by myself to the south of the vertical circle passing through the radiant, and in this case the limits of azimuth were correspondingly extended.

The several enumerations are contained in the following table, in which the beginning and end of each watch is expressed in mean solar time of the meridian 90° west of Greenwich. The dates are given to tenths of a day.

1898	Watch		Number of Leonids	Obs'r	Remarks
	Beginning	Ending			
Nov. 10.6	$13^h\ 30^m$	$14^h\ 0^m$	3	C.	All faint
	14 33	15 3	4	C.	One second magnitude
	15 30	16 0	5	C.	One second magnitude
	16 30	17 0	2	C.	Moon interferes slightly
Nov. 10.7	17 30	18 0	1	C.	Strong twilight
11.5	12 0	12 30	0	Ch.	Sky partly overcast
	12 30	13 0	0	Ch.	
	13 0	13 55	1	Ch.	Clouds disappear at $13^h\ 30^m$
	14 0	14 50	1	Ch.	
	15 0	15 30	2	C.	
	16 0	16 30	4	C.	All meteors on this night are faint
Nov. 11.7	17 0	17 30	0	C.	save two of second magnitude
12.5	12 0	13 0	0	Ch.	Hazy and partly overcast
	13 0	15 0	1	Ch.	Clouds
Nov. 12.7	15 0	17 0	1	C.	Clouds
13.5	12 0	15 0	0	Ch.	Clouds
13.7	15 0	17 0	0	C.	Clouds
14.5	12 0	12 30	9	C.	
	12 0	12 30	10	Ch.	All bright. Trails
	13 0	13 30	13	Ch.	
	14 0	14 30	21	Ch.	
	15 0	15 30	29	C.	
	16 0	16 30	23	C.	
Nov. 14.7	17 5	17 35	19	C.	A fine clear night
15.5	12 0	12 30	1	C.	
	13 0	13 30	4	C.	
	14 0	14 30	4	C.	
	15 0	15 30	5	C.	Three of third magnitude
	16 0	16 30	2	C.	
Nov. 15.7	17 0	17 30	1	C.	Doubtful Leonid
16.5	12 40	15 30	1	Ch.	Doubtful Leonid

On November 14 the observer notes: About one-half of the meteors are brighter than second magnitude and of a golden-yellow color, with short trails. During the last watch of this night a fireball was seen near the zenith, brighter than Jupiter and leaving a trail which lasted about a minute (estimated), drifting with the wind, and becoming convex in the direction of its motion.

It appears from the numbers in the foregoing table that there is a well marked maximum of meteor frequency on November 14 at approximately $21^h\ 30^m$ Greenwich M. T., the number at this time being nearly if not quite 60 per hour. The width of the meteor stream and the rate at which the density falls off of either

side of the central line are to be derived, of course, from a combination of all of the observed data, but it appears probable from the above that there is an appreciable diminution in density within an hour's motion of the Earth on either side of the maximum and that the total diameter of the denser central aggregation does not exceed twelve hours of such motion. The observations of November 10 suggest a feeble outlying stream to the west of the main body of meteorites but the evidence for this needs to be supplemented by other observations.

As a subsidiary part of the observing programme I planned a determination of the radiant of the swarm as follows: If a long straightedge be brought between the eye and the heavens so as apparently to coincide with the path of a meteor, it will also pass through the radiant, and since, in the present case, the radiant is nearly surrounded by a ring of stars, the Sickle, if the points at which the straightedge crosses this ring be noted and transferred immediately to a chart, a straight line drawn through these points will pass through the position of the radiant upon the chart, and the intersections of several such lines will determine this position. A gnomonic projection, with its pole near the radiant, is best adapted for such a chart, since all great circles of the heavens are represented upon it by straight lines. If the meteor paths were plotted directly upon such a chart, considerable error might arise from the effect of distortion in the outer parts of the projection, and it was to avoid the effect of such distortion operating upon the unavoidable errors of observation that it was determined to transfer the meteor paths to the radiant by means of the straightedge seen against the background of the heavens.

Since no such chart was available, I have constructed one by computing and plotting for all naked-eye stars near the radiant the polar coördinates, r, a', of their projections from the center of the celestial sphere upon a plane tangent to it at the assumed position of the radiant, *i. e.*, the point whose coördinates for the epoch 1855 are $\alpha_0 = 149.0°$, $\delta_0 = +23.0°$, using the following formulæ, in which α and δ are the coördinates of the stars for

the same epoch. The prime radius from which a is reckoned is the great circle drawn from the point a_0, δ_0, to the south pole, and the quantity r is expressed in radians:

$$A = a - a_0 \qquad r \sin a' = \tan A \cos \theta \sec (\delta_0 - \theta)$$
$$\tan \theta = \tan \delta \sec A \qquad r \cos a' = \tan (\delta_0 - \theta)$$

In the hope that others may use the plan here outlined, I give below the coördinates of all the stars in question which are brighter than the fifth magnitude:

Star	a'	Log. r
α Leonis,	6° 19′	9.264
η Leonis,	8 22	8.990
γ Leonis,	57 39	8.888
ζ Leonis,	112 4	8.734
μ Leonis,	214 29	8.898
κ Leonis,	245 2	9.237
ϵ Leonis,	250 7	8.891

From the plotted chart (scale, 1mm = 5′) a number of copies were taken upon tracing paper, each copy showing only the positions of the stars without indication of the coördinates employed, and a single copy was used for plotting a limited number of meteor paths, from three to eight, and was then replaced by a fresh sheet in order that the plotting of subsequent observations might not be biased by the previous record. The radiant determined by the intersections on each sheet was subsequently transferred back to the original chart by pricking through the sheet, and the coördinates carefully measured.

From ten meteor paths, observed as above by Mr. Chandler and myself on November 14 and 15, I find for the position of the radiant, R.A. = 147.5°, Dec. = + 21.3°, and from eight paths observed by myself on November 14 and plotted by eye estimate only, without the aid of the straightedge, I find 151.5°, + 21.6°. The correction for zenith attraction is included in these numbers. I consider the first result to be the better of the two. In each of these determinations the plotted paths appear to radiate from a circular area within the Sickle, having a

diameter of about three degrees. The difference in the two determinations of the right ascension of the radiant given above I am inclined to regard as systematic and arising from the different methods employed for prolonging the meteor paths to the radiant, but the amount of data is, of course, insufficient to furnish a definitive conclusion in this respect.

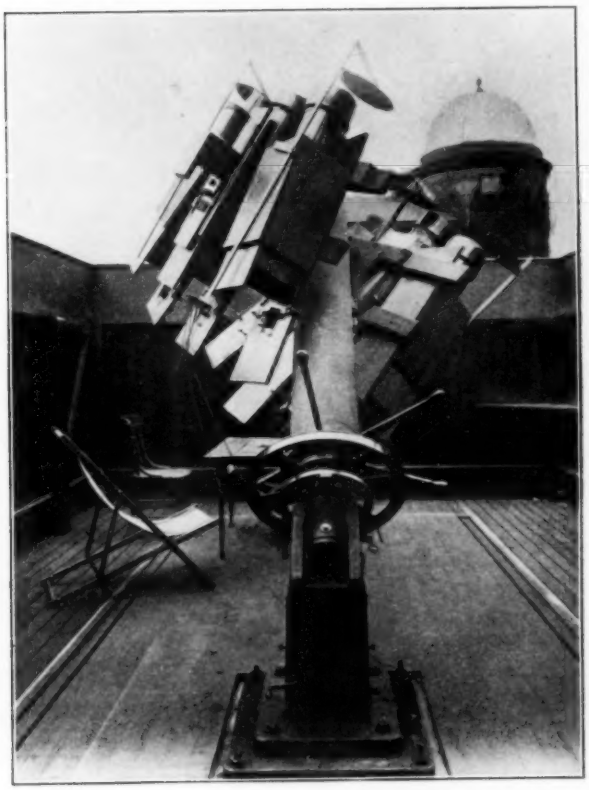
WASHBURN OBSERVATORY,
Madison, December 1898.

PHOTOGRAPHIC OBSERVATIONS OF THE LEONIDS AT THE YALE OBSERVATORY.

By W. L. Elkin.

The photographic apparatus at the Yale Observatory, designed mainly for the purpose of attempting to secure records of meteor trails, was put up in 1894 with the aid of a grant from the J. Lawrence Smith fund of the National Academy of Sciences. It consists of a long polar axis driven by clockwork and arranged for carrying a number of cameras. At present it is equipped with six large cameras carrying portrait lenses of from six to eight inches aperture and twenty-seven to thirty-six inches focus,—three of which are of Voightlaender make and were presented to the Observatory by Cyprian S. Brainerd, Esq., of New York,—and with two smaller cameras with four-inch lenses. With a further grant from this same fund this year a second station was put up distant about two miles from the Observatory in a northerly direction. The apparatus at this station was of a more simple nature: a wooden polar axis without clockwork, but furnished with a toothed wheel with 144 teeth in place of an hour circle. The stars were allowed to trail over the plates, but every ten minutes the axis was advanced one tooth, so that the same field as before would still be covered. The axis was furthermore placed out of adjustment with reference to the pole, so that the successive star trails fell alongside each other. Knowing the time when any meteor appeared it is easy to refer its trail to the position of the stars at that time. This instrument carried four cameras with similar portrait lenses of about five inches diameter, and was in charge of Dr. Chase with an aid, while at the Observatory Mr. Brown, our secretary, Mr. Smith, photographic assistant, and myself were on duty; Mr. Lewis, of Ansonia, kindly aiding on one evening.

Watch for the Leonids was kept on the nights of November 12 to 16 inclusive. On November 12 it was clear from about



THE YALE OBSERVATORY METEOROGRAPH.

16 hours on and plates were exposed for about one hour in the Observatory instrument. Some fifteen Leonids were seen, but no trails secured. November 13 and also 16 were completely overcast at New Haven all night, but the 14th and 15th were clear throughout and the complete programme was carried out at both stations. Plates were exposed from $11^h\ 15^m$ to about $17^h\ 20^m$ each night, two in each of the Observatory cameras and three in each of those at the secondary station — about twelve hours in all, therefore. On November 14 quite a display of Leonids occurred, 118 being noted by the Observatory party besides thirty-six meteors from other radiants, while on November 15 only thirty Leonids were noted against forty-two others. Of all these, some twenty-four were possibly in the field of the cameras, and up to now we have found nine trails on the Observatory plates and seven on those of Dr. Chase's station, four meteors having been recorded at both places (Plate I).[1]

The value of these photographic records can naturally only be estimated when the trails are fully measured and discussed; an interesting by-product of the work came soon to light, however, when, on examining the plates on November 21, Dr. Chase noticed a faint elongated object showing displacement on the four successive plates of one of the Observatory cameras, and proving to be a faint comet presumably first photographed here.

[1] A very faint meteor trail on this plate was lost in the process of reproduction.

THE NOVEMBER METEORS AT URBANA, ILLINOIS.

By G. W. Myers.

The coördinates of the University Observatory are as follows: radius of the Earth, $r = 0.998675$, the longitude, $\lambda = 5^h\ 52^m\ 54.59^s$ W. of Greenwich, the latitude, $\phi = +\ 40°\ 6'\ 20.6''$, and the altitude above the sea, $h = 740$ ft.

It was the original purpose here to observe the Leonid meteors this year continuously from November 11 to November 16, but the carrying out of this purpose was very seriously interfered with by cloudy weather. Systematic observations were, however, begun at 11:30 P.M. on the 11th, and continuous watch was kept upon the sky from 11:00 P.M. to daybreak until the morning of the 15th. To ascertain with certainty whether the Earth had gotten entirely out of the swarm by the 16th, watch was kept from 11:00 P.M. on the 15th to 3:30 A.M. on the 16th. We feel, therefore, that we have about all the observational material on the 1898 shower which could have been obtained visually, under the circumstances, in our locality. The sky remained perfectly clear and black on the night of November 11th–12th; but on the 12th–13th it was uniformly cloudy, with the exception of about an hour from 2:50 to 3:50 A.M. on the latter date. The dense cloudiness of the sky remained unbroken on the night of the 13th to the 14th. No first magnitude stars could be seen at any time during the entire night. From 11:15 to 3:15 on the night of November 14th–15th the sky was more or less overcast; but, at the end of this interval, it began to clear up and within another half hour it was practically clear, and remained so till morning. On the following night, however, the sky was clear during the entire night, and the comparatively small number of meteors counted from 11:30 until 3:30 A.M. convinced us we had gotten entirely through the swarm. While, therefore, it cannot be contended that we saw all that actually happened in the upper regions of those parts of

the atmosphere lying along the line of sight to the Leonid radiant, it is certainly true that fully as much occurred as was seen and recorded, which is a virtue unfortunately not always attaching to astronomical observations made in these latter days.

Three observers participated in the observational part of the work, viz., Assistants Brenke and Coffeen and the writer. The method of observing was substantially that suggested in the pamphlet issued by Harvard College Observatory last autumn. One observer gave his undivided attention, for ten to fifteen minutes, to a region of the sky within 25° of the radiant point, as located by Denning, noting the color, magnitude, time of appearance of meteors, and whether the meteor was a Leonid or a "non-Leonid." During this time, while the other two were "off duty," they gave their attention to the more careful study of individual meteors. One of the observers "off duty" then took his turn "on duty" and so on, during the entire night. During these leisure intervals 27 meteoric paths were drawn on charts, which had been previously prepared, and these paths were afterwards transferred through tracing paper to a single sheet. A sheet made in this way from the observations of November 14–15, containing the above mentioned 27 paths, is reproduced in Fig. 1. No great value can be ascribed to it, the paths not being sufficiently numerous to warrant general conclusions, though those drawn seem to indicate pretty conclusively that the radiant is an area and not a point, and that the center about which the prolonged paths intersect is of lower declination than Denning gives it (+ 22.9°). On the chart made by the writer and containing 10 carefully located paths, two points were quite clearly indicated from which meteors radiated more plentifully than from surrounding regions. These points are indicated on the accompanying chart by the symbol (⊹). One of these points is in Long. $9^h\ 50^m$, Dec. + 20°, and the other in Long. $10^h\ 14^m$, Dec. + 23°. As a matter of course, no great confidence can be put in the indications of so small a number of recorded paths, and the writer mentions this feature only to suggest the idea to another, who may have been more fortunate

in the number of recorded trains than he was, that the Leonid radiant may be *double*. A chart of 12 paths made by one of the other two observers suggested this same peculiarity in a marked

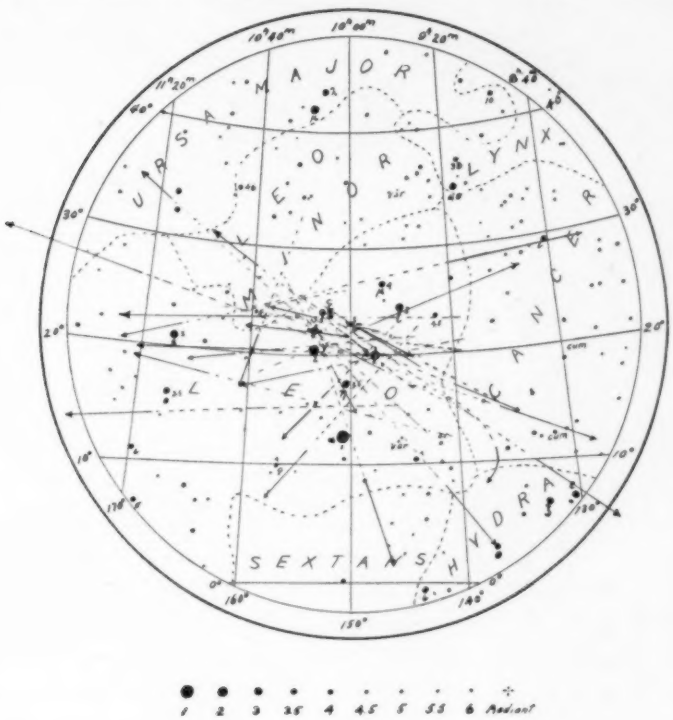


FIG. 1.

degree, though it was not apparent on the chart of the third observer.

The observations made on the mornings of November 12 and November 15, which were practically all we obtained, are given in the six tables below.

The time employed throughout is that of the 90th meridian W. of Greenwich. The correction of the clock used in these observations, which may be of service to some one in identifying some of the paths, was on the 11th–12th $= -21^s$, and on the 14th–15th $= -22^s$.

TABLE I.

FREQUENCY OF METEORS AT URBANA, NOVEMBER 11–12, 1898.

90th Mer. time	O	L	N	T	90th Mer. time	O	L	N	T
12:20–12:27	M	0	0	0	15:02–15:10	C	0	1	1
:27– :35	C	0	1	1	:10– :22	M	3	2	3
:35– :45	B	0	1	1	:22– :35	B	3	2	5
:45– :55	M	1	1	2	:35– :45	M	1	2	3
:55–13:05	C	1	1	2	:45– :55	C	0	1	1
13:05– :16	B	0	1	1	:55–16:05	B	2	1	3
:16– :25	M	1	0	1	16:05– :15	M	1	1	2
:25– :35	C	1	0	1	:15– :30	C	4	4	8
:35– :45	B	3	0	3	:30– :40	B	1	0	1
:45– :55	M	0	0	0	:40– :50	M	1	1	2
:55–14:05	C	0	1	1	:50–17:00	C	3	4	7
14:05– :20	B	2	2	4	17:00– :15	B	5	2	7
:20– :35	C	1	1	2	:15– :30	C	2	4	6
:35– :51	M	3	3	6	:30– :55	B	1	1	2
14:51–15:02	B	0	2	2					
					Total	....	40	39	79

The first column of Tables I and IV gives the intervals during which the observer, whose initial is in the second column, was "on duty." The third column contains the number of Leonids seen in this interval, the fourth the number of meteors from other sources, and the fifth the total number. The average hourly number of meteors counted during the entire interval of $5^h\ 35^m$ on the night of the 11th–12th, is seen from Table I to be 14. Considering the fact that the attention was directed to a rather limited region of the sky, and that we were then getting almost twice as many meteors hourly as under ordinary circumstances, we may pretty safely infer that the Earth was then in the Leonid swarm. The average hourly number for the 14th–15th was 27, 81 per cent. of which were Leonids. Meteors were appearing at a maximum rate about 4:45 A.M. on the morning of the 15th, when not less than two per minute were counted for about ten minutes.

The last column of Table II shows the same sort of a double maximum as was observed by Professor W. H. Pickering on the night of the 13th–14th last year (1897). The cloudy interval

from 1 : 15–2 : 15 on the 15th prevents us from deciding whether or not it is present in Table V. The rising percentage of Leonids toward daybreak on the 15th, as given in Table IV, would suggest that the maximum was probably passed during the day.

TABLE II.

METEORIC COUNTS GROUPED IN HOUR INTERVALS, NOVEMBER 11–12, 1898.

Interval	L	N	T	P
12 : 20–13 : 20	3	5	8	38%
13 : 20–14 : 20	6	3	9	67
14 : 20–15 : 20	6	8	14	43
15 : 20–16 : 20	10	7	17	59
16 : 20–17 : 20	13	11	24	54
17 : 20–17 : 55	2	5	7	30

TABLE III.

MAGNITUDE AND COLOR OF METEORS, NOVEMBER 11–12, 1898.

Class	5	4	3	2	1	0	−1	−2	+S	+J	Total	W	Y	Om.	Total
L	11	7	12	3	3	0	1	0	0	1	38	26	2	13	40
N	10	8	7	8	4	2	0	0	1	1	41	13	3	23	39
Total	21	15	19	11	7	2	1	0	1	2	79	39	5	35	79
Per cent.	27	19	24	14	9	3	1	0	1	2	100	50	6	44	100

From Tables III and VI it is impossible to pronounce with certainty whether, on the whole, Leonids are brighter, or fainter, than other meteors, since the average magnitude for November 11th–12th is, for the Leonids, 4.0; for the non-Leonids, 3.2; while on the 14th–15th it is, for the Leonids, 2.2, and for the non-Leonids, 2.6. In computing these averages, we have omitted the bright meteors in columns headed + S and + J (*i. e.*, as bright as Sirius or brighter, and as bright as Jupiter or brighter), since the estimates of brightness for these meteors

TABLE IV.

FREQUENCY OF METEORS AT URBANA, ILL., NOVEMBER 14–15, 1898.

90th Mer. time	O	L	N	T	90th Mer. time	O	L	N	T
11:15 to 11:29	M	3	3	6	16:00 to 16:13	B	11	2	13
:29 to :45	C	1	2	3	:13 to :29	M	12	3	15
:45 to 12:00	B	2	0	2	:29 to :40	C	12	5	17
12:00 to :15	M	7	3	10	:40 to :50	B	15	0	15
:15 to :30[1]	C	1	0	1	:50 to 17:00	M	12	4	16
:30 to 14:20[2]					17:00 to :10	C	12	4	16
14:20 to :45[3]	M	4	0	4	:10 to :20	B	13	1	14
:45 to 15:00[3]	B	2	0	2	:20 to :30	M	12	3	15
15:00 to :15[3]	C	1	0	1	:30 to :40	C	3	1	4
:15 to :31[1]	M	5	1	6	:40 to :50	B	2	0	2
:31 to :45[1]	B	14	0	14	:50 to 18:00[4]	M	1	0	1
16:45 to 16:00	C	4	2	6					
					Total		149	34	183

[1] Signifies "hazy," fourth magnitude stars being visible.

[2] No meteors seen. Dense clouds.

[3] Signifies the interval was generally cloudy, the clouds being broken here and there.

[4] Signifies dawn had advanced so far that no stars could be seen.

TABLE V.

METEORIC COUNTS GROUPED BY HOUR INTERVALS, NOVEMBER 14–15, 1898.

Interval	L	N	T	P
11:15–12:15.....	13	8	21	62%
12:15–13:15[5].....	8	3	11	73
13:15–14:15[5].....	0	0	0	
14:15–15:15[5].....	7	0	7	100
15:15–16:15.....	26	6	32	81
16:15–17:15.....	70	16	86	81.4
17:15–18:00...	23	4	27	85

[5] Signifies that the interval was seriously interfered with by clouds.

was felt to be very uncertain. From the latter parts of Tables III and VI we find the percentage of yellow to white meteors to be for the Leonids, $\frac{1}{13}$; and for the non-Leonids, $\frac{3}{13}$ for the 12th–13th; and on the 14th–15th, for the Leonids, it is $\frac{9}{40}$; for

the non-Leonids, $\frac{15}{40}$. These figures seem to indicate that the percentage of white to yellow meteors is considerably greater for the Leonids than for the meteors from other radiants. It is, at least, markedly true on these two evenings and is more markedly so as the number of Leonids rises.

TABLE VI.

MAGNITUDE AND COLOR OF METEORS, NOVEMBER 14–15, 1898.

Class	5	4	3	2	1	0	−1	−2	+S	+J	Total	W	Y	Om.	Total
L.....	7	24	32	39	34	4	6	3	0	1	150	119	27	4	150
N.....	1	10	5	8	7	1	0	0	0	1	33	21	8	4	33
Total.....	8	34	37	47	41	5	6	3	0	2	183	140	35	8	183
Per cent.....	4	18	20	26	22	3	4	2	0	1	100	76	29	5	100

Remark.—The writer has from more than one observed phenomenon been made to feel that the common idea that the Mississippi valley is necessarily a bad location for an astronomical observatory is without foundation; but never more forcibly than on the mornings of the 12th and 15th of November last. Two hours before sunrise on both of these mornings the zodiacal light was seen delineated on the dark background of the celestial vault with all the distinctness with which it is depicted by observers in equatorial regions. The outlines of the pyramidal sheaf of light could have been traced with little difficulty, the apex rising quite to the meridian or even beyond it, completely enveloping the planet Mars. The color of the light was white, with perhaps a pale greenish cast. The base reached from a point on the eastern horizon 10° or more north of east, around toward the south to a point 30° to 40° south of east. The glow from the light was so strong as actually to interfere with the meteoric observations we were at the time engaged in.

Work was begun on the Bielid meteors on the evening of November 16th. The watch was kept up continuously from 6:00 P.M. until 11:00 P.M. on every evening to the 29th. Nothing of the

swarm was seen on either the 23d or the 27th, or on any intervening date. On the evening of the 17th, however, from 10:00 to 11:00 P.M., ten meteors were counted at this Observatory, and all emanated from the region of the Andromid radiant. The Moon was within 30° of the radiant, being at the time about five days old. Its light doubtless cut out half of the meteors which would have been seen without it. This estimate is probably too low in the present instance, since the obliterating effect of a general haze was also present, so that we were, on this evening, receiving Andromids at a rate of not less than twenty per hour. Is it not just possible that the swarm may have been accelerated this year as it was in 1892, despite the mathematical necessities of the situation? Clouds interfered with further observation at this time.

NOTES ON THE SPECTRUM OF *o* CETI.

By W. W. CAMPBELL.

THIS interesting variable star was placed on the Mills spectrograph observing list solely for the purpose of determining its velocity in the line of sight. The observations were not expected to contribute to our knowledge of the star's physical condition. The spectrograph is designed for recording spectra in the $H\gamma$ region exclusively. The photographs of the spectrum of *o* Ceti show the details of the portion between λ 4270 and λ 4440, on a scale large enough to permit an accurate determination of the wave-lengths. As is well known, the dark-line spectrum of this star is of Secchi's third type, and bright hydrogen lines $H\gamma$, $H\delta$, $H\zeta$, $H\eta$, etc., are also present.

The velocity of the star, obtained from measures of the dark-line spectrum on seven plates, is as below:

1897	November	10	+63.3km	1898	August	29	+62.8km
	*		+63.5		September	4	+63.7
	December	15	+62.0		September	19	+61.8
	December	15	+60.9		November	29	+62.3
	*		+60.5				
					Mean		+62.3km

The velocity furnished by the dark-line spectrum seems to be constant.

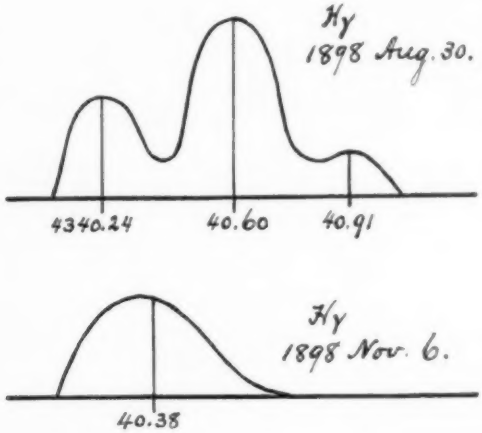
The bright $H\gamma$ band is extremely strong; in fact, very much overexposed, on all the plates referred to above. If an exposure of an hour was required for recording the dark-line spectrum, an exposure of two minutes, under the same conditions, would record the $H\gamma$ band.

The bright $H\gamma$ band is displaced toward the violet with reference to the dark-line spectrum. This is unmistakably evident from all the photographs. The amount of the *apparent* displacement depends upon the degree of exposure. The red edge of the band fades away gradually, while the violet edge terminates

rather sharply. Therefore, with increased exposures, the apparent center of the band moved toward the red. The centers of the overexposed images of $H\gamma$ occupied positions corresponding to the following velocities:

1897	November	10	+58km	1898	August	29	+59km
	*		58		August	30	56
	December	15	53		September	4	56
	*		50		September	4	59
	December	15	52		September	19	54
	*		53		September	19	56
1898	August	29	57		November	29	48

The two photographs of December 15, 1897, and that of November 29, 1898, were taken sometime after the maxima for the two years, when the brightness of the star was much reduced. The smaller velocities recorded for those dates are due in part to the reduced intensity of the $H\gamma$ band, but principally to real changes in the character and position of the band, as explained below.



The first short exposure plate, for giving suitable density to the $H\gamma$ band, taken August 29, 1898, showed that the band was made up of three bright lines. The middle line was the strongest. The one to the violet was fairly strong, and the one to the red was relatively weak. None of the lines seemed to be strictly

monochromatic; the red one especially seemed to be poorly defined. The appearance of the band at that time is represented in the accompanying intensity curve for August 30.

The wave-lengths of the three maxima were measured on three plates and reduced to the system of the dark-line spectrum, assuming that spectrum to yield a velocity of + 62.3km per second with reference to the solar system; and the apparent velocities corresponding to the positions of the three maxima have been computed from their displacements with reference to the comparison spectra. It is not contended that the displacements represent actual velocities of the incandescent hydrogen in the line of sight. It is quite conceivable that the displacements are due to pressure, or to other causes. The results are reduced to velocity, since that is a convenient and homogeneous method of comparing displacements in the $H\gamma$ and $H\delta$ bands with those in the dark-line spectrum. The results for the triple $H\gamma$ band are as below.

1898 Aug. 29		Aug. 30		Sept. 4		Means	
λ	V	λ	V	λ	V	λ	V
4340.22	+ 35km	4340.24	+ 35km	4340.25	+ 36km	4340.24	+ 35km
.59	+ 59	.60	+ 60	.61	+ 61	.60	+ 60
.96	+ 85	.87	+ 79	.91	+ 81	.91	+ 82

Inasmuch as all our photographs showed the center of the $H\gamma$ band to be displaced toward the violet with reference to the dark-line spectrum, it was desirable to examine the bright $H\delta$ band for evidence bearing on the same point. Mr. Wright secured two photographs of it in September. They show the $H\delta$ band to be triple, with a very strong central component as in $H\gamma$, but with the other components about equal to each other. It was seen at a glance that the principal component was displaced more toward the violet with reference to the hydrogen comparison line that was the case for the principal component of the $H\gamma$ band. The plate contained comparison lines of the artificial iron and hydrogen spectra. The velocity of the principal com-

ponent of the $H\delta$ band determined from a direct comparison with the $H\delta$ comparison line was about + 49km per second; but determined from the neighboring comparison lines of iron, it was about + 40km, assuming the normal position of the $H\delta$ line to be that assigned by Rowland's Table, λ 4102.000. We suspected an error in the assigned wave-length, and the matter was investigated by Mr. Wright. His result for the wave-length—published on another page of this JOURNAL—is 4101.89. Using this value, the velocities determined from the hydrogen and iron lines agreed. The results for the $H\delta$ band are as below, the

1898 Sept. 4		Sept. 22		Means	
λ	V	λ	V	λ	V
4101.40	+ 26km	4101.36	+ 23km	4101.36	+ 23km
.33*	+ 21*	.35*	+ 23*		
4101.72	+ 50	4101.71	+ 49	4101.69	+ 48
.68*	+ 47*	.66*	+ 46*		
4102.16	+ 82	4102.14	+ 81	4102.14	+ 80
.13*	+ 80*	.11*	+ 78*		

wave-lengths being expressed in terms of the normal values for the lines in the dark-line spectrum—the displacements being converted into velocity for convenience in making comparisons. It will be noticed that the first and second lines in the $H\gamma$ and $H\delta$ bands are displaced by unequal amounts—12km. The third lines in the two bands were of quite different character.

There is good reason to believe that an additional bright line exists at λ 4102.8, and one or two others at about the same distance to the violet of $H\delta$, though there is a possibility that these may be abnormally bright points in the continuous spectrum.

Photographs of both bands taken in November of this year showed that their character had changed, and that the $H\gamma$ band had shifted its position to a remarkable degree. The bands seemed to be composed of single lines, not monochromatic, with possibly a very faint companion on the red side of each, as

shown in the illustration for November 6, above. The wave-lengths of the $H\gamma$ band, determined from six plates, and the velocities with reference to the solar system, are the following:

1898 November 6	4340.37	+44.0km
November 7	.38	+45.0
November 8	.37	+44.4
November 29	.34	+42.0
November 29	.39	+45.4
November 29	.39	+45.8
Means	4340.37	+44.4km

One plate of the $H\delta$ band gave the results:

1898 November 8	4101.68	+47km

The $H\gamma$ and $H\delta$ bands agreed closely in appearance and in displacement in November, but were perceptibly different in appearance and very different in displacement at the times of the August and September observations.

As the continuous spectrum grows fainter, several additional bright lines seem to become visible. One deserves special mention. Its wave-length in the system of the dark-line spectrum, and the corresponding velocity in the line of sight, on the assumption that its normal wave-length is that of the iron line λ 4376.107, have been determined as below.

1897 November 7	4375.82	+42km
November 8	.84	+44
November 16	.83	+43
November 22	.84	+44
November 29	.87	+46
Means	4375.84	+44km

This line would seem to be displaced the same amount as the hydrogen bright bands.

Another apparent bright line is at λ 4307.78. If we assume its normal wave-length to be that of the strong iron line at λ 4308.081, its displacement is such as to correspond to a velocity of +42km, the same as for the other bright lines.

The photographs show many other features which would no doubt be of great interest; but I shall not discuss them, preferring rather to confine the investigation to the determination of velocities in the star's system. At the same time, to avoid possible misunderstanding, it is well to repeat that the displacement of the bright lines toward the violet, with reference to the dark-line spectrum, and the changed velocities assigned to them, must not be considered as proving actual changes in the velocity of the matter emitting the bright-line spectrum. It is quite conceivable that changes in the physical condition of the body are responsible for the *apparent* changes of velocity.

A majority of the photographs of this star's spectrum were secured by Mr. Wright, and the results marked thus * are from his independent measures and reductions.

On December 12 the visual spectrum of this star was examined by Professor Keeler, Mr. Wright, and myself, especially in the vicinity of the hydrogen lines. The $H\gamma$ and $H\delta$ lines were prominent. With reference to the strength of their continuous-spectrum background, the $H\delta$ line seemed to me to be stronger than the $H\gamma$ line. I was unable to see any evidence of a bright $H\alpha$ or $H\beta$. However, the spectrum seemed to be full of details in those regions, and weak hydrogen lines, which easily escape visual detection, might be visible on large-scale photographs.

LICK OBSERVATORY,
December 14, 1898.

CONSIDERATIONS CONCERNING THE INFLUENCE OF A MAGNETIC FIELD ON THE RADIATION OF LIGHT.[1]

By H. A. LORENTZ.

1. THE assumption that every molecule of a source of light contains a single movable ion, which can be displaced in all directions from its position of equilibrium and is always driven back to that position by the same force, proportional to the displacement, leads to the elementary theory of the phenomenon discovered by Dr. Zeeman. Viewed across the lines of force, a single spectral line must, by the action of the field, be tripled, and viewed along the lines of force, be doubled; besides, the components of the triplets and doublets must be polarized in a well-known manner.

Whilst the first observations of Zeeman were consistent with this theory, and he soon could confirm the theoretical predictions by the observation of distinct triplets and doublets, yet it has become apparent that the case is often less simple. For instance, Cornu proved that in the case of one of the sodium lines, viewed across the lines of force, the central component of the triplet is doubled, so that in reality a quadruplet is seen. Michelson and Th. Preston observed in many cases not only a far more complicated structure of the central component, but a similar structure of the outer components of the triplet. According to these observations, the word "triplet" is hardly applicable, though there is always an important difference between the central part of the appearance in the spectrum (the two central lines, for instance, of Cornu's quadruplet) and the outer parts; the first is plane polarized, the plane of polarization being perpendicular to the lines of force, whereas in the right and left part the plane of polarization is parallel to the lines of force.

2. The facts mentioned evidently make it necessary to replace

[1] *Proceedings of the Royal Academy of Sciences*, Amsterdam, June 25, 1898.

the elementary theory by a more complete one. Some time ago, I examined[1] therefore what phenomena are to be expected, if a molecule, having an arbitrary number of degrees of freedom and arbitrarily distributed electric charges, is oscillating about a position of equilibrium.

Before returning to this subject, I will consider the conclusions which may be obtained by arguments from symmetry, without entering into the details of the mechanism of radiation.

There can be no doubt that we may consider the source of light as a system of extremely small particles, oscillating partly with the frequency of the light vibrations; in virtue of their electric charges, these particles must excite in the surrounding ether periodically oscillating dielectric displacements. These constitute the luminous motion radiated by the source.

For briefness' sake this entire system will be indicated by S.

We may now conceive a second system S', which is the image of S, relatively to a fixed plane P. The meaning of this is as follows.

If A is a particle in S, there is in S' a particle A', which is the image of A and of the same physical nature as this particle. Especially, the mass and the electric charge are the same; or, to speak more accurately, in corresponding points of A and A' the same material density and the same density of electric charge will be found. Moreover, the particles A' will be *at every moment* the image of the particles, A, or, as we may say, the motion of the ions in S' will be the image of the motion in S. If this is the case, the luminous motion in the ether in S' will likewise be the image of the motion in S, in this sense that the vector representing the dielectric displacement in S' is always the image of a corresponding vector in S.

Of course all this will only be possible, if the forces operating on the particles A' are the images of those to which the particles A are subjected. So far as the *mutual* action of the particles is concerned, we may regard this as a consequence of the supposed equality in physical nature. In order that the

[1] *Wied. Ann.*, **63**, 278, 1897.

forces, originated by the external magnetic field, may satisfy the same condition, we will suppose that the vectors, representing the magnetic force in S', may be derived from the corresponding ones in S by first taking their images, and then reversing the directions of these images.[1]

It will also be assumed that the properties of the image of the source of light, as far at least as we are concerned with them in really observable phenomena, are the same as those of the source itself, so that the latter may be substituted for the image. Finally, we suppose that the entire luminous motion in the ether is developed by means of Fourier's theorem into simple harmonic motions; when the total luminous motions in S and S' are each other's images, the same will evidently be true of those parts of the luminous motions, which have a determinate period T—or rather periods between two definite limits T and $T+dT$.

3. Let Q be a straight line, drawn from any point in the source of light parallel to the lines of force, and let L denote the luminous motion *with a definite period* T, existing at a distant point of Q. By taking the image of the whole system, relatively to a plane parallel to the line Q, it is easily seen that the image L' is exactly the luminous motion that would exist in the point considered, if, the source of light remaining unchanged, the direction of the field were reversed. Hence L' may very well differ from L, but, in all observable properties, L' must remain unchanged, if the reflecting plane be turned around the line Q as axis.

Whence it follows, that, if all vibrations of L are resolved parallel to a line R, perpendicular to Q, the intensity produced by the components must be independent of the direction of R. Indeed, R_1 and R_2 being two lines perpendicular to Q, and I_{r1} and I_{r2} the intensities corresponding to them in the manner indicated, we may give to the reflecting plane two positions, P_1 and P_2, in such a way that the image of R_1, relatively to P_1,

[1] If the magnetic field is generated by electric currents, we may imagine the required field in S' to be produced by currents, which are the images of the currents in S.

coincides with that of R_2, relatively to P_2. Indicating by R' the direction of these coinciding images and by I'_r the intensity corresponding to this direction of vibration in L'—this quantity remaining the same, as was remarked above, for every position of the reflecting plane—we may write $I_{r1} = I'_r$ and $I_{r2} = I'_r$; hence $I_{r1} = I_{r2}$.

In this way we come to the conclusion that the light propagated along the lines of force, and having a definite period T, or, in other words, occupying a definite place in the spectrum, cannot be polarized plane or elliptically, neither completely, nor partially. It can only be unpolarized, or circularly polarized; in the latter case the polarization can be partial as well as complete.

The light would be unpolarized, if an influence of the magnetic field did not exist at all. As far as we know, the components of the doublets seen along the lines of force are completely circularly polarized. From the above considerations it however appears that the radiation might also be partially circularly polarized. We see at the same time that, if in a given place of the spectrum the polarization is right-handed, it must become left-handed at the same place by reversing the magnetization.

4. Arguments of the same kind may be used when the observations take place across the lines of force. Now, we place the reflecting plane perpendicular to these lines. The magnetic field remains unchanged; consequently, the luminous motion must have the same properties as its image. Hence the light, observed in a given place of the spectrum, cannot be circularly nor elliptically polarized—neither completely nor partially. It must be either unpolarized light, or plane polarized—wholly or in part—the plane of polarization being parallel or perpendicular to the lines of force.

It needs scarcely be mentioned, that all observations are in agreement with this conclusion.

5. A closer examination of the mechanism of radiation gives us a relation between the light radiated along and that radiated

across the lines of force. At least one conclusion concerning this point lies at hand.

Let M be a single molecule of the source of light, and let three rectangular axes, OX, OY, OZ be drawn, the first along the lines of force. Let e be the electric charge in a point of the molecule having the coördinates x, y, z; then we may call $\Sigma e x$, $\Sigma e y$, $\Sigma e z$—calculated for the entire molecule—the components of the electric moment of the particle.

These quantities are continually changing, and will perhaps be extremely complicated functions of the time. By means of Fourier's theorem, we may however separate the parts that have a determinate period T. We will confine ourselves to these parts and denote them by $\mathfrak{m}x$, $\mathfrak{m}y$, $\mathfrak{m}z$.

If now the dimensions of the molecule are very small compared with the wave-length, then, the observer being supposed at a distance of a great many wave-lengths, it may be deduced from theory, that in all points of OY, light is produced merely by the variations of $\mathfrak{m}x$ and $\mathfrak{m}z$, $\mathfrak{m}x$ producing vibrations along, and $\mathfrak{m}z$ across the lines of force. Similarly for points of OX and OZ.

Suppose that, when viewing across the lines of force, for instance from a point of OY, in a given place of the spectrum light is seen which is entirely plane polarized, the plane of polarization being perpendicular to the lines of force.

Then, at the place in question, there will not be any luminous motion produced by $\mathfrak{m}z$, and, because the molecules are vibrating independently of each other and hence light emitted by one can never be totally destroyed by that originating from another, $\mathfrak{m}z$ must vanish in all molecules. Of course the same argument applies to $\mathfrak{m}y$; hence it follows, that no light can be observed from any point of OX, that is to say in the direction of the lines of force.

Becquerel and Deslandres have found[1] that one of the iron lines, when viewed across the lines of force, becomes a triplet, the central and side components of which, as compared with

[1] *Comptes Rendus*, 4 avril 1898.

those of the ordinary triplets, have interchanged their states of polarization.[1] The foregoing reasoning entitles us to predict, that only the middle component of this triplet will be visible, when the phenomenon is observed in the direction of the lines of force.

6. In the paper cited above, I have established the equations of motion for infinitely small vibrations of a molecule, having n degrees of freedom, and placed in a magnetic field. I called $p_1, p_2 \ldots p_n$ the general coördinates, chosen in such a manner, that they are 0 in the position of equilibrium, and that they are principal coördinates as long as there is no external magnetic force. I obtained for the equations of motion

$$\left.\begin{aligned} a_1 \ddot{p}_1 + b_1 p_1 - (c_{1.2}\dot{p}_2 + c_{1.3}\dot{p}_3 + \ \ldots \ + c_{1.n}\dot{p}_n) = 0, \\ a_2 \ddot{p}_2 + b_2 p_2 - (c_{2.1}\dot{p}_1 + c_{2.3}\dot{p}_3 + \ \ldots \ + c_{2.n}\dot{p}_n) = 0, \end{aligned}\right\} \qquad (1)$$

etc., where a and b are constants, independent of the magnetic force.

The influence of the field is expressed by means of the terms containing the quantities c, which are all proportional to the intensity of the field.

They further satisfy the relations

$$c_{r.s} = -c_{s.r} \qquad (2)$$

To determine the possible periods of vibration, we put, according to a known method, in (1):

$$p_1 = \mu_1 e^{\lambda t}, \quad p_2 = \mu_2 e^{\lambda t}, \quad \ldots \quad p_n = \mu_n e^{\lambda t},$$

and eliminate $\mu_1, \mu_2, \ldots \mu_n$. If

$$\frac{b_1}{a_1} = k_1^2, \quad \frac{b_2}{a_2} = k_2^2, \quad \ldots \quad \frac{b_n}{a_n} = k_n^2,$$

and

$$\frac{c_{r.s}}{a_r} = -e_{r.s},$$

the result may be put into the form

[1] The same phenomenon has been observed in the case of some iron lines by AMES, EARHART and REESE, *Johns Hopkins Univ. Circulars*, Vol. 17, No. 135.

$$\begin{vmatrix} l^2+k_1^2, & e_{1.2}\,l, & e_{1.3}\,l, & \ldots & e_{1.n}\,l \\ e_{2.1}\,l, & l^2+k_2^2, & e_{2.3}\,l, & \ldots & e_{2.n}\,l \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ e_{n.1}\,l, & e_{n.2}\,l, & e_{n.3}\,l, & \ldots & l^2+k_n^2 \end{vmatrix} = 0 \qquad (3)$$

In consequence of the relation (2), the development of the determinant will contain only even powers of l^2. Hence an equation is obtained, of the n^{th} degree in l^2. From the circumstances of the case it follows, that the roots of this equation are all real and negative; hence n pairs of imaginary values of l are obtained. If $+ik'_r$ and $-ik'_r$ are two of those values, there will be a mode of vibration with the frequency (number of vibrations in the time 2π) k'_r.

Evidently, without the field, the frequencies would become

$$k_1, \quad k_2, \quad \ldots \quad k_n,$$

and it is clear that, if there is a magnetic field, each of these frequencies is modified into a value k'_r, differing very slightly from k_r.

In the cited paper I had restricted the development of (3) to terms containing the products of two factors e. Denoting by Π the product

$$(l^2+k_1^2) \quad (l^2+k_2^2) \quad \ldots \quad (l^2 \times k_n^2)$$

and by $\Pi_{r.s}$ the value, got from this by omitting the factors $l^2+k_r^2$ and $l^2+k_s^2$, we obtain

$$\Pi - \Sigma\, l^2\, e_{r.s}\, e_{s.r}\, \Pi_{r.s} = 0, \qquad (4)$$

where the sum is to be extended to all combinations of unequal indices r and s.

I inferred from this equation, that a triplet can only be observed, if three of the values k are equal, or, in other words, if the system has three equivalent degrees of freedom. This will also be clear when it is considered, that by a continuous decrease of the magnetic field, the three components of the

triplet may be made to coincide, so that the simple spectral line, as seen out of the field, may be considered as consisting of three coinciding lines. Applying the same argument to Cornu's quadruplet, it seems natural to suppose that the lines, which are apt to undergo this modification, consist already, under ordinary circumstances, of four coinciding lines, or otherwise, that now we have four equivalent degrees of freedom, or four equal values k.

Yet the origin of a quadruplet cannot be explained by equation (4). Indeed, if k_1, k_2, k_3, k_4 are the frequencies having the same value k, there are in each term of (4) at least two factors $l^2+\mathrm{k}^2$. Hence the equation must still have two equal roots $-\mathrm{k}^2$, and besides only two roots, differing very little from $-\mathrm{k}^2$.

7. It was however brought to the notice of the author by Mr. A. Pannekoek that in this case equation (4) is incomplete, because some of the terms neglected are of the same order of magnitude as those retained, and that, by returning to equation (3), an explanation of the quadruplet may be arrived at.

If $k_1^2=k_2^2=k_3^2=k_4^2=\mathrm{k}^2$, certainly four roots of equation (3), if not $=-\mathrm{k}^2$, will differ only very little from this value.

If l^2 is one of these values (we need not occupy ourselves with the other values of l^2), then the four quantities $l^2+k_1^2$, $l^2+k_2^2, l^2+k_3^2, l^2+k_4^2$ will be small. On the other hand the quantities

$$l^2+k_5^2, \quad l^2+k_6^2, \quad \ldots \quad l^2+k_n^2 \tag{5}$$

will have values, which by no means become small. Since all the quantities $e\,l$ are likewise small, the elements (5) of the determinant will exceed by far all other elements, and we shall obtain a sufficient approximation, when we take in the development of the determinant only those terms, which contain all the quantities (5). Evidently, the equation serving for the determination of the values of l^2, which differ only slightly from $-\mathrm{k}^2$, will therefore be

$$\begin{vmatrix} l^2+k^2, & e_{1.2}\,l, & e_{1.3}\,l, & e_{1.4}\,l \\ e_{2.1}\,l, & l^2+k^2, & e_{2.3}\,l, & e_{2.4}\,l \\ e_{3.1}\,l, & e_{3.2}\,l, & l^2+k^2 & e_{3.4}\,l \\ e_{4.1}\,l, & e_{4.2}\,l, & e_{4.3}\,l, & l^2+k^2 \end{vmatrix} = 0.$$

If we develop this determinant, all terms, which have an odd number of factors $e_{r.s}l$, are excluded by (2). Hence the equation may be written

$$(l^2+k^2)^4 + A\,(l^2+k^2)^2 + B = 0, \tag{6}$$

where A contains terms with two factors $e_{r.s}l$, and B terms with four factors of this kind. In all these factors l^2 may be replaced by $-k^2$. Consequently, A and B can be found, and A is now proportional to the square and B proportional to the fourth power of the intensity of the field.

From (6) we get two values of $(l^2+k^2)^2$, which are both real and positive, because, as was already remarked, real values must be found for l^2. Hence the solution of (6) may be represented by

$$(l^2+k^2)^2 = \alpha^2, \tag{7}$$

and

$$(l^2+k^2)^2 = \beta^2, \tag{8}$$

where α and β are known, say positive, quantities. By reason of what has been remarked about A and B, the values of α and β will be proportional to the intensity of the field.

Finally from (7) and (8) the following *four* values of l^2 are obtained:

$$l^2 = -k^2+\alpha, \quad -k^2-\alpha, \quad -k^2+\beta, \quad -k^2-\beta,$$

so that in fact there must be seen a quadruplet in the spectrum. In order that the four lines of this quadruplet may be perfectly sharp, it is however necessary, that in a given magnetic field the quantities α and β are independent of the direction into which the molecule is turned, or, what comes to the same thing, that, for a given position of the molecule, α and β are independent of the direction of the magnetic force.

Mr. Pannekoek has also remarked, that a similar reasoning applies when an arbitrary number, *e. g.*, p, frequencies k are equal. In this case we come to the conclusion that, for a given position of the molecule in the field, the simple spectral line must be separated into a p-fold line, in such a way, that the position of the different components is symmetrical to the right and left of the original line. From this it follows, that if p is odd, one component remains at the place of the original line.

It seems however very difficult to conceive a system, having really, as is necessary for quadruplets, four equivalent degrees of freedom, especially if in addition to this, it is required that the values of α and β must be independent of the direction of the magnetic force, relatively to the molecule. I have not been able to find out a system really fulfilling these conditions. It is true, it might be argued that the very existence of a quadruplet *proves* the equality of four frequencies, when there is no magnetic field, and hence that the above theory of the quadruplet must be true, even though the mechanism has not yet been found out. However, I have some scruples about adopting this view of the case, for I think it is not yet quite certain that the vibrations which produce light are really to be described by equations of the form (1).

ON AN ASYMMETRY IN THE CHANGE OF THE SPECTRAL LINES OF IRON RADIATING IN A MAGNETIC FIELD.[1]

By P. ZEEMAN.

1. IT is known that in the elementary treatment of the influence of magnetic forces on spectral lines according to Lorentz's theory it is sufficient, if only one spectral line is considered, to suppose that in every luminous atom is contained one single movable ion moving under an attraction proportional to the distance from its position of equilibrium. All motions of such an ion can be resolved into linear vibrations parallel to the lines of force and two circular vibrations, right-handed and left-handed, perpendicular to the lines of force. The period of the first mentioned vibration remains unchanged, those of the last are modified, one being accelerated and the other retarded. The doublets seen along the axis of the field, the triplets seen across it are in this manner simply explained and also the observed polarization phenomena. Besides we must expect according to the theory that the outer components of the triplet are of equal intensity and likewise the two circularly polarized components of the doublet. Eye observations as well as the negatives taken by myself and others have always confirmed till now this most simple symmetrical distribution of intensities. The question arises, cannot the external magnetic forces, sufficient to direct the molecular currents assumed in the ionic theory of magnetism,[2] favor the circular vibrations more than those along the lines of force.[3] If this be assumed we are also compelled to admit that

[1] *Proceedings of the Royal Academy of Sciences*, Amsterdam, June 25, 1898.

[2] *Cf.* RICHARZ, *Wied. Ann.*, **52**, 385, 410, 1894.

[3] *Cf.* LORENTZ, *Versl. Ak. Amsterdam*, October 1897, p. 213. [It was pointed out by Lorentz in the article referred to, that the phenomena observed by Egoroff and Georgiewsky can be explained, without any hypothesis of the kind mentioned, by the absorption which the rays from the posterior part of the flame undergo in the anterior part.

the revolution of the ions takes place more in a given direction than in the contrary. Hence then there must be a difference of intensity between the two outer components of the triplet and between the two components of the doublet. Although the ordinary magnetism of the highly-magnetic substances has probably disappeared in the spark, it seems rather natural to examine in the first place iron, nickel and cobalt in search of a phenomenon in which the "molecular currents" of Ampère (or that part of these currents, which is produced by the motion of the light-ions) would manifest themselves optically. However, it seems to me by no means decided beforehand, that other substances would not exhibit something of this kind. I have however investigated in the first place iron.

The first results obtained were very promising. In the field used several of the iron lines exhibited on the negatives a more intense component at the less refrangible side of the spectrum. Further inquiry has however shown that this seemingly positive result seems to be of no value. I will give the results of my experiments only in abstract. Before describing them, it may be remarked, that, if a directing influence, as mentioned, exists, we must expect that the component at the less refrangible side must be intensified in the case of the triplet as well as in that of the doublet. The sign of the charge of the ions cannot have any influence upon this result.

2. Negatives were taken in the spectra of the third and second orders obtained by means of a Rowland grating (radius 10 feet, 14,438 lines to the inch). The part of the spectrum between 3000 and 4000 A. U., when viewed in the two principal directions across and along the lines of force, was studied with special care. The vast majority of the iron lines were, with the field used, resolved into doublets, triplets, quadruplets, etc.; only three or four lines seemed unaffected. Now I found in the case of a few lines inequality between the outer components of a triplet across and of the corresponding doublet along the lines of force. On the negative the component at the red side of the spectrum was darker, independently of a commutation of the

current. Of course the difference of intensity is dependent upon the time of exposure. Upon some of the negatives the difference was for a special line perhaps 50 or 100 per cent.

However it was plain enough, that the outer component of the triplets and also the two components of the doublets were, in the case of the *strong* iron lines, of equal intensity. Now in the case of feebler lines, one of which we will call L, perturbations will be possible due to the overlapping of one of the components of a "normal" triplet or doublet and a feeble line, say but slightly affected by magnetism. The latter line can (1) be present near L in the same spectrum; or (2) belong to a spectrum of another order from the line L; or (3) by the very presence of the field a special line may become relatively to other lines more intense or a new line may be produced. By taking negatives with different fields it will, of course, be possible to avoid difficulties from these three causes, at least if the supposed line is narrow. We can, however, by taking also negatives in absence of the field exclude (1), and by taking negatives in spectra of different orders or by cutting off any interfering spectrum through the use of absorbents, (2). Having done this, it appeared that case (3) also sometimes occurs; the intensity of the iron lines relatively to the air lines varies considerably and the mutual intensity of the iron lines appreciably. New lines appear, at least lines absent on negatives taken with the field off became distinctly visible, while the intensity of the field was still insufficient to resolve the lines into triplets, etc.

The last mentioned perturbation is of course most deceptive. Using however fields of varying intensities, I could avoid perturbation (3). Excluding however (1), (2), (3), only triplets, doublets, etc., remained, which, I think, can only be called quite symmetrical. Hence up to the present time there is no evidence of a directing influence of the magnetic field on the orbits of the light-ions.[1]

[1] *Cf* PRESTON, *Phil. Mag.*, **45**, 333, 1898.

Minor Contributions and Notes.

THE VELOCITY OF METEORS.

The considerable success that has attended the efforts to photograph meteor trails recently shows that it would be possible to measure the velocity of a meteor by a photographic method. All that is required is to arrange a rotating toothed wheel in front of the camera and to know the rate of rotation and number of teeth, so that there may be two or more eclipses of the meteor during the passage of its image across the plate. Another possible arrangement would be to give an oscillatory or other motion to the plate, to the lens, or to a mirror reflecting the light into the camera. These latter arrangements would, however, distort the images of fixed stars, and are consequently less desirable than a simple eclipser.

The actual velocity of meteors is only roughly known, and it would be of great interest to determine it accurately. The method indicated would probable enable this to be done sufficiently accurately to determine whether there is any sensible change in the velocity owing to the resistance of the atmosphere.

I have often felt surprise that this method has not, to my knowledge, been employed before. I have tried on several occasions to get it tried by astronomers over here, but the prospect of being able to photograph the trails at all seemed to deter them. I can hardly think that the proposal is familiar to American astronomers, or it would probably have been used during the recent showers, but I have seen no record of its having been tried, so that I now write this in hope that observations of this kind may be made next year.

Geo. Fras. Fitzgerald.

Trinity College,
Dublin, December 28, 1898.

ON THE WAVE-LENGTH OF THE $H\delta$ LINE.

In measuring the displacement of the $H\delta$ line in the spectrum of the star o Ceti, the spectra of both hydrogen and iron have been used for comparison. In the case of hydrogen the shift is directly meas-

urable. When the iron comparison is used the value of the micrometer reading for $H\delta$ must be interpolated from the readings on the iron lines. Using for this purpose the wave-lengths given in Rowland's *Preliminary Table of Solar Spectrum Wave-lengths*, it was noticed by Professor Campbell and myself that the interpolated and direct readings did not agree.

An error in Rowland's value of the wave-length of $H\delta$ ($\lambda = 4102.000$) was suspected, and two determinations of this quantity were made with the Mills spectrograph.

Plate 1019 D. — The spectrum of hydrogen was photographed with that of the sky on each side for comparison. Close solar lines were used as standards, with the following results:

Standard	$H\delta$	
4098.335	4101.89	Corrected for curvature of spectrum lines and motion of Earth.
4103.097	01.90	
04.288	01.90	
	4101.90	

Plate 1018 D. — The position of the $H\delta$ absorption line was measured with reference to neighboring solar lines.

Standard	$H\delta$	
4100.315	4101.89	
00.901	01.87	
03.097	01.90	
04.288	01.89	Mean 4101.89
	4101.88	

These values agree more closely than do Rowland's with those obtained by Dr. Ames and other investigators.

W. H. WRIGHT.

LICK OBSERVATORY, UNIVERSITY OF CALIFORNIA,
December 14, 1898.

THE NOVEMBER METEORS IN 1898.[1]

OBSERVATIONS of the meteoric shower of November 13, 1897, were made at the Harvard College Observatory, and a description of the results will be found in the *Annals*, Vol. XLI, No. 5, and in *Circular*

[1] *Harvard College Observatory Circular* No. 35.

No. 31. More extensive observations were made in 1898, and the results will be published later in the *Annals*. Several investigations were undertaken, and some of the preliminary results are given below. As proposed in *Circular* No. 31, stations have been selected all around the Earth, in order that counts of the number of meteors visible might be made during the entire time that the Earth traversed the meteor stream. The density of different portions of the stream would thus be determined. Reports from the distant stations will not be received for some time. The night of November 13 was cloudy in Cambridge, but on November 14, 800 meteors, not including duplicates, were recorded at this Observatory by 30 persons. The maximum occurred at three o'clock in the morning, when 61 meteors east of the meridian were counted in half an hour; 227 trails of 80 different meteors, within 30° of the radiant point, were charted. Similar observations were made at Providence by Professor Upton of the Ladd Observatory, aided by a number of students. The vicinity of the radiant was watched continuously by at least ten observers, who recorded 400 meteors. This station is 40 miles south of Cambridge, and was selected as suitable for determining the parallax visually. Ninety-six photographs were taken at Cambridge with the Draper telescopes and with eleven smaller instruments. Five photographic doublets were mounted equatorially and photographed the region within 30° of the radiant during nearly the entire night. Two cameras were carried to Tufts College, two miles north of Cambridge, and twenty-five photographs were taken simultaneously at both stations for a photographic determination of the parallax. In all, 31 trails of eight different meteors were photographed, of which 3 appeared on one plate. Four meteors were photographed at both stations, and can be used for determining the parallax photographically. The changing distance of the meteors is obvious by inspection of these photographs. A preliminary determination of the radiant was made by prolonging the trails of 4 meteors. They nearly intersect in a point, the greatest deviation not exceeding 1^{mm}, or 10′. The position of the radiant reduced to 1900 is thus given as R.A. $= 10^h\ 6.8^m$, Dec. $= +22°16'$, which is 9^m following, and 38′ south of the place given by Denning. Seventeen plates were taken with prisms, but they failed to show the spectra of any meteors. It appears from the photographs that the light of the meteors attained a maximum and then diminished as rapidly as it increased. In some cases, sudden changes due to explosions are well

shown. The trail is sometimes surrounded by a sheath of light, and in one case the trail remaining after the meteor had passed was photographed. These results show that meteoric showers may now be studied to advantage by photography.

EDWARD C. PICKERING.

November 19, 1898.

WITT'S PLANET (433), D Q.[1]

A CAREFUL search has been made by Mrs. Fleming upon the Harvard plates for early photographs of Witt's planet (433), D Q. Mr. S. C. Chandler has courteously furnished ephemerides based upon the best available material, and has devoted much time to correcting the elements and computing the positions corresponding to the times at which certain photographs were taken, as is more fully explained in the *Astronomical Journal*, No. 452.

In making this search the following method of procedure has been adopted: Mr. Chandler, by means of the elements published in the *Astronomical Journal*, No. 451, computed ephemerides for the oppositions of 1894 and 1896. It appeared that the observations then available were insufficient to determine the position in 1894. An error of 1″ in the mean daily motion in the orbit would change the right ascension of the object in 1894 by about half an hour. Moreover, the value of the daily motion differed by several seconds not only in the early ephemerides of this planet, but in those dependent on a large number of visual observations. Although plates were examined by Mrs. Fleming, covering a region of about 1300 square degrees, the planet was not found. Plates taken in 1896 were next examined, as it was thought that the smaller errors of the ephemeris would compensate for the extreme faintness of the planet. This examination proved to be especially laborious and fatiguing to the eyes. It was feared that the object might be too faint to appear upon the plates, and accordingly the faintest objects were carefully scrutinized.

Each plate was examined by superposing it upon another plate of the same region taken with the same instrument. Two adjacent images then appeared of each star, while the planet, if present, would appear only on the upper plate. Numerous suspicious objects were thus found, including several images of the planets Flora (8) and Nysa (44), and two new variable stars, whose approximate positions for

[1] *Harvard College Observatory Circular* No. 36.

1900 are in R. A. 8^h 33.9^m, Dec. + 50° 29′ and R. A. 18^h 38.7^m, Dec. — 38° 52′, were discovered. The star + 29° 551 fails to appear on ten plates which show other faint *Durchmusterung* stars, and two stars at R. A. 9^h 11.4^m, Dec. — 10° 43′ and R. A. 9^h 11.5^m, Dec. — 10° 16′ appear upon the *Durchmusterung* charts and upon the photographic plates, but are not given in the *Durchmusterung* catalogue.

At last a faint image was found on a plate taken on June 5, 1896, and confirmed by other plates taken on June 4 and 5. A plate taken on April 6 covered the region of the planet, which was readily found by means of its computed position. Mr. Chandler, from positions of these images, was enabled to furnish a corrected ephemeris for 1894, by means of which the planet was readily detected on several plates. The positions so far found are given below. The successive columns give the number of the plate, the date, the Greenwich Mean Time of the middle of the exposure, the length of exposure in minutes, the approximate right ascension and declination for 1875, and the number of comparison stars used in the determination of the position. The instrument used is indicated by the letter in the first column, A denoting the 24-inch Bruce telescope which was then in Cambridge, B the 8-inch Bache telescope in Arequipa, and I the 8-inch Draper telescope in Cambridge. The method of measurement is that described in the *Harvard Observatory Annals*, Vol. XXVI, p. 228.

Plate	Date			G. M. T.		Ex.	R. A. 1875			Dec. 1875			Comp.
	y	m	d	h	m	m	h	m	s	°	′	″	
I 10215	1893	12	19	18	21	14	7	45	57.0	+ 54	38	41	5
I 10215	1893	12	19	18	21	14	7	45	57.5	+ 54	38	37	5
I 10321	1893	12	27	17	32	10	7	44	43.2	+ 50	54	45	6
I 10321	1893	12	27	17	32	10	7	44	42.8	+ 50	54	43	6
I 10353	1894	1	1	17	09	59	7	41	34.5	+ 47	34	±	7
A 246	1894	2	16	14	49	12	7	29	58.3	— 0	21	45	11
A 246	1894	2	16	14	49	12	7	29	58.1	— 0	21	41	11
B 10909	1894	4	16	14	13	10	9	17	0 ±	— 13	34	15 ±	7
B 10951	1894	4	18	14	29	10	9	21	48 ±	— 13	39	1 ±	7
B 15531	1896	4	6	20	52	60	18	37	0.3	— 38	32	51	6
B 15531	1896	4	6	20	52	60	18	37	0.5	— 38	32	48	6
B 16108	1896	6	4	16	40	70	18	30	5.3	— 40	2	46	9
B 16157	1896	6	5	19	54	10	18	27	51.0	— 39	58	17	9
B 16165	1896	6	5	22	04	11	18	27	39.1	— 39	57	53	9
B 16165	1896	6	5	22	04	11	18	27	39.7	— 39	58	8	9

I 10321. Image 4° from center of plate and therefore distorted, but shows direction of motion.

I 10353. Spectrum plate, showing that the spectrum of this object, like that of the other planets and of the Sun, is of the second type.

A 246. Image much distorted and elongated.

B 16108. Image much elongated owing to rapid motion.

B 16157 Image very faint, near edge of plate, and therefore much distorted, but shows motion by comparison with B 16165.

The following ephemeris and elements have been computed by Mr. Chandler, by combining the observations of 1898 with those derived from the photographs taken December 19 and 27, 1893, February 16, 1894, April 6, 1896, and June 4 and 5, 1896.

ELEMENTS.

Epoch 1898, August 31.5, Gr. M. T

$M = 221^\circ\ 35'\ 45.6''$

$\omega = 177^\circ\ 37'\ 56.0''$

$\Omega = 303^\circ\ 31'\ 57.1''$ } 1898.0.

$i = 10^\circ\ 50'\ 11.8''$

$\phi = 12^\circ\ 52'\ 9.8''$

$\mu = 2015.2326''$

$\log a = 0.1637876$

Period $= 643.10^d$

A comparison of the observed positions with those obtained by computation is given below. The successive columns contain the date, the Greenwich Mean Time, the apparent right ascension and declination, and the corrections to the ephemerides published in the *Astronomical Journal*, and that given above. The approximate value of the true anomaly is given in the last column.

Date			G. M. T.		Apparent R. A.			Apparent Declination			O−C		O−C		v
											R. A.	Dec.	R. A.	Dec.	
y	m	d	h	m	h	m	s	°	′	″	m	s	′	s	′	°
1893	12	19	18	21	7	47	29.4	+54	35	50	.	...	..	+3.5	0.0	— 30
	12	27	17	32	7	46	11.3	+50	51	57	.	...	..	—0.7	—0.3	— 23
1894	1	1	17	09	7	42	59.8	+47	31	±	.	...	..	—1.9	—1.0	— 19
	2	16	14	49	7	30	57.8	—	0	24	9	...	..	+5.1	—1.0	+ 22
	4	16	14	13	9	17	54.0	—13	39	16	.	.	..	+7.6	+0.2	+ 69
	4	18	14	29	9	22	42.6	—13	42	2	.	...	..	+7.4	+0.4	+ 71
1896	4	6	20	52	18	38	30.1	—38	31	42	—0	36.0	—4.8	+3.0	+1.3	+115
	6	4	16	40	18	31	37.4	—40	01	52	—1	16.7	—5.9	+0.9	+1.5	+142
	6	5	19	54	18	29	23.1	—39	57	28	—1	16.4	—5.6	+1.2	+1.8	+142
	6	5	22	04	18	29	11.5	—39	57	11	—1	16.7	—5.8	+0.9	+1.7	+142

EPHEMERIS FOR GREENWICH MIDNIGHT AND EQUINOX OF 1894.0.

Date	R. A. 1894.0	Dec. 1894.0	v	log r	log Δ	Mag.
	h m s					
1893 Oct. 27.5	5 56 22	+53° 18.6′	−71° 28.3′	0.1120	9.6713	9.86
31.5	6 8 15	54 15.0				
Nov. 4.5	6 20 3	55 4.8	−65 49.4	.1038	.6254	9.59
8.5	6 31 39	55 49.6				
12.5	6 43 0	56 28.4	−59 57.6	.0958	.5778	9.31
16.5	6 53 56	57 0.4				
20.5	7 4 18	57 25.1	−53 52.8	.0881	.5285	9.02
24.5	7 13 59	57 41.3				
28.5	7 22 48	57 47.9	−47 35.4	.0809	.4772	8.73
Dec. 2.5	7 30 29	57 43.8				
6.5	7 36 54	57 27.4	−41 5.7	.0743	.4240	8.43
10.5	7 41 52	56 56.6				
14.5	7 45 19	56 8.8	−34 24.6	.0684	.3692	8.13
18.5	7 47 15	55 1.5				
22.5	7 47 41	53 31.0	−27 33.4	.0634	.3141	7.83
26.5	7 46 44	51 34.2				
30.5	7 44 37	49 7.4	−20 33.5	.0594	.2615	7.55
1894 Jan. 3.5	7 41 34	46 7.8				
7.5	7 37 59	42 34.5	−13 26.9	.0565	.2170	7.31
11.5	7 34 15	38 28.9				
15.5	7 30 45	33 55.4	− 6 15.8	.0548	.1890	7.16
19.5	7 27 46	29 1.3				
23.5	7 25 30	23 58.6	+ 0 57.5	.0543	.1850	7.14
27.5	7 24 6	19 0.1				
31.5	7 23 34	14 15.9	+ 8 10.5	.0552	.2065	7.25
Feb. 4.5	7 24 0	9 55.0				
8.5	7 25 20	6 1.3	+15 20.7	.0572	.2475	7.47
12.5	7 27 37	+ 2 37.3				
16.5	7 30 46	− 0 18.0	+22 25.7	.0604	.2994	7.74
20.5	7 34 41	2 46.8				
24.5	7 39 17	4 51.6	+29 23.5	.0647	.3551	8.04
28.5	7 44 31	6 35.4				
Mar. 4.5	7 50 20	8 1.0	+36 12.1	.0699	.4111	8.35
8.5	7 56 41	9 10.7				
12.5	8 3 32	10 8.5	+42 50.3	.0760	.4654	8.65
16.5	8 10 48	10 55.3				
20.5	8 18 29	11 33.2	+49 16.8	.0828	.5175	8.94
24.5	8 26 30	12 4.0				
28.5	8 34 50	12 29.1	+55 30.9	.0901	.5672	9.23
Apr. 1.5	8 43 25	12 49.3				
5.5	8 52 15	13 5.8	+61 32.2	.0979	.6147	9.50
9.5	9 1 18	13 19.6				
13.5	9 10 34	13 31.3	+67 20.6	.1059	.6604	9.77
17.5	9 19 59	13 41.8				
21.5	9 29 33	−13 51.7	+72 56.1	0.1142	9.7043	10.03

The brightness for 1898, August 24.5 is taken as 11.5 (log r = 0.2396, log Δ = 9.8722).

The residuals O—C′ show that the object on each plate was surely the planet. They by no means represent the accuracy to be expected, either incomputation when the perturbations of the Earth are included, or in measurement when time permits the use of more precise methods. Images have since been found on plates taken November 26 and December 23, 1893, and January 19, January 25, January 30, and February 5, 1894.

EDWARD C. PICKERING.

December 26, 1898.

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The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

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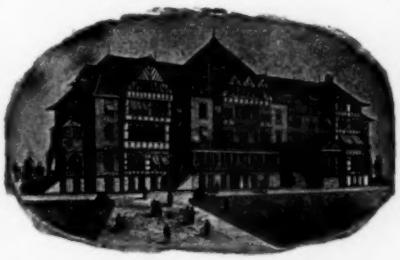

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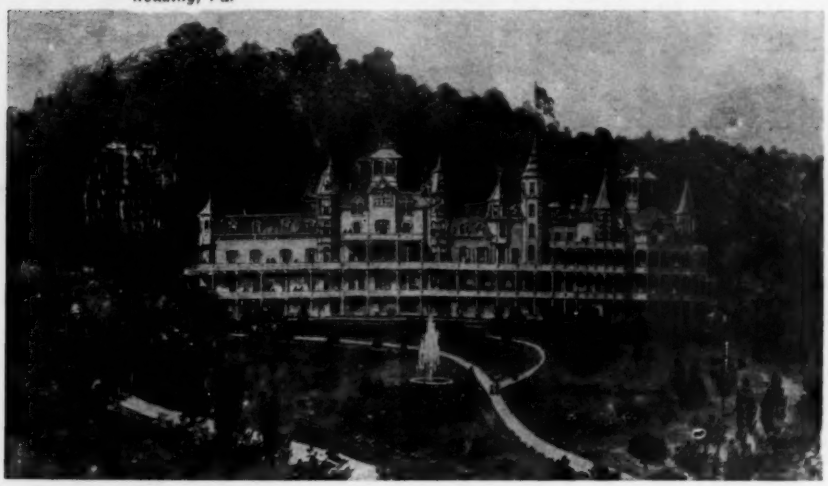

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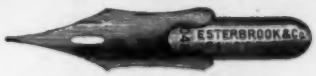

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